

MEMORY SYSTEM

This invention is concerned with improvements in or relating to memory systems.

In recent years, computer systems have exhibited major advances in speed and in miniaturization at significant reduction in cost. Concurrent with these advances have been major efforts to develop information storage and retrieval systems which are also low cost and still compatible with the high speeds with which these new systems operate. Much of this effort has been directed toward the development of optical disc memory devices because of their rapid write time ($>1\text{M}$ bit per second), rapid access time (<0.1 sec.), high density ($>1.5 \times 10^7$ bits per sq. cm), and low cost ($\sim 10^{-4}$ cents per bit). (See Kenny, et al., IEEE Spectrum, pages 33-38, February 1979.) To date, numerous types of materials have been developed for optical discs; however, most of these have the disadvantage of storing information permanently; i.e., they cannot be erased

or edited. (See R. A. Bartolini, et al., IEEE Spectrum, pages 20-28, August 1978).

(Materials which are exceptions to this general rule appear to fall into the following classifications: certain thermoplastics, photochromics, chalcogenides, magneto-optical materials, photoferroelectric materials, photoconductive/electro-optical materials and electro-optic materials. However, each of these has significant disadvantages. For example, thermoplastics such as polyvinylcarbazole/polystyrene require a pre-exposure corona charge. In addition, they use surface relief storage which has a relatively low contrast ratio, a long erase time, difficulties in local erase, and a short lifetime (~100 cycles). Photochromics such as spiropyran typically require blue or ultra-violet light for write and/or erase and hence are not compatible with present semiconductor lasers. Furthermore, most photochromics are subject to fatigue, which severely limits cycle lifetime, and the stored data tends to fade in just a few minutes. Chalcogenides such as TeAsGe typically exhibit a low cycle lifetime (~10 cycles) and have a relatively low contrast ratio for erasable media. Magneto-optical materials such as the rare earth iron garnets usually require an external magnetic field. Materials with the largest magneto-optical effects (garnets) require micro-patternning to get high density storage and have high optical

insertion loss. Photoferroelectrics can be fabricated as ceramic materials but the ceramics are subject to fatigue. Photoconductive/electrooptic materials such as $\text{Bi}_{12}\text{SiO}_{20}$ have limited data storage times, on the order of several hours, and also require large single crystals. Electro-optic materials such as LiNbO_3 also require single crystals and stored information is erased during readout unless the image is thermally fixed whence another thermal treatment is required for erasure.

10 The use of liquid crystal materials, particularly smectic liquid crystals is well known in the prior art for certain display devices, and stationary memory systems have been developed which use this media for information storage. (See U.S. Patent No. 3,796,999 entitled Locally Erasable
15 Thermo-Optic Smectic Liquid Crystal Storage Displays; and Dewey, et al., SID 77 Digest, 108 (1977).) However, the prior art does not indicate the development of any liquid crystal devices which can function under large accelerations to provide rapid access to data (in a computer disc
20 application, a liquid crystal could experience accelerations exceeding $30,000\text{m/sec}^2$ depending on the disc size and the desired data rate). The obvious flow-related problems associated with liquids in general suggests that liquid crystals could not be used in optical disc-type memory
25 systems, where large rotational velocities are necessary to

achieve the desired data input-output rates. Indeed, rotational velocities exceeding 10,000 rpm may be desirable for some applications.

Furthermore, one approach to information storage in smectic liquid crystals is to create radiation scattering defects in the liquid crystal medium. Such an approach, in light of the specific physical characteristics of defects in these crystals would seem to indicate that in a rotating system, smectic liquid crystals would have severe problems with information stability. For example, it is expected that the cores of defects in smectic liquid crystals structurally approach the isotropic phase and hence have a measurably lower density than the smectic phase (10.1%, see S. Torza and P. E. Cladis Phys. Rev. Letters, 32(25), 1406(1974)). It would therefore be reasonable to expect significant defect motion or even destruction of the defect (information) pattern in the liquid crystal as a result of centrifugal forces developed at high angular velocities. It would also be reasonable to expect fluid motion to occur during the startup and slowdown phases, further destroying any information-containing defect systems.

Other studies on the structure of defects in homeotropically aligned smectic layers have shown that the information-carrying defects are focal conics which form polygonal arrays spanning the liquid crystal cell (see

C. S. Rosenblatt, R. Pindak, N. A. Clark, R. B. Meyer, J Physique 38(9), 1105(1977)); such arrays could be expected to be quite susceptible to any fluid motion. Furthermore, other literature has shown cell dilatations of the order of 5 100 Angstroms are sufficient to cause spontaneous formation of polygonal focal conic defect arrays. (See N. A. Clark, Phys. Rev., A14, 1551 (1976).) With such extreme sensitivity to dilatations, the formation of such polygonal focal conic arrays could be expected to develop at high 10 angular velocities, thereby destroying any information pattern contained in the liquid crystal medium.

For all of these reasons, the use of liquid-crystal materials in a rotating data storage system has not heretofore been suggested in the art.

15 The present invention provides an information storage and retrieval device comprising a liquid crystal disc memory comprising confinement means for confining a liquid crystal medium, said confinement means being configured for rotation about an axis, a liquid crystal 20 medium confined by said confinement means, said liquid crystal medium having localized spots therein which act as radiation scattering centers, said spots being created by local heating of said liquid crystal medium and representing a desired pattern of information; reading means for detect- 25 ing radiation scattered from individual spots; and rotating means for rotating said confinement means and said liquid crystal therein relative to said reading means, to provide

high speed access to said information by said reading means.

In a device as set forth in the last preceding paragraph, it is preferred that said liquid crystal medium comprises a smectic liquid crystal.

5 A device as set forth in either one of the last two immediately preceding paragraphs, may further comprise at least two electrodes on said liquid crystal disc memory for applying an electric field to said liquid crystal medium, alignment means for aligning said liquid crystal
10 medium, and absorber means in thermal communication with said liquid crystal medium for absorbing a portion of radiation incident on said absorber means and for supplying energy from said radiation to said liquid crystal medium.

A device as set forth in the last preceding para-
15 graph may further comprise reflector means for reflecting a portion of radiation incident thereon.

A device as set forth in the last preceding paragraph may further comprise heat control means for controlling the relative distribution of energy conducted from said
20 absorber means to said liquid crystal medium and from said absorber means to said confinement means.

A device as set forth in any one of the last three immediately preceding paragraphs may further comprise heat control means for controlling the relative distribution of
25 energy transferred from said absorber means to said confinement means and from said absorber means to said liquid crystal medium.

In a device as set forth in any one of the last four immediately preceding paragraphs, it is preferred that said confinement means further comprises two substrates between which said liquid crystal medium is sandwiched.

5 In a device as set forth in the last preceding paragraph, it is preferred that said electrodes are located opposite each other with said liquid crystal medium therebetween; and said alignment means and absorber means are comprised of at least one film located between said sub-
10 strates.

In a device as set forth in either one of the last two immediately preceding paragraphs, it is preferred that said heat control means comprises at least one film located between said liquid crystal medium and at least one of said
15 substrates.

In a device as set forth in either one of the last three immediately preceding paragraphs, it is preferred that said reflector means comprises at least one film located between said liquid crystal medium and at least one of said
20 substrates.

A device as set forth in any one of the last ten immediately preceding paragraphs may further comprise means for writing information onto said disc memory and/or erasing information stored on said disc memory.

25 A device as set forth in the last preceding paragraph may further comprise writing means for locally irradiating a small area of said liquid crystal medium to create

radiation scattering defects therein.

A device as set forth in either one of the last two immediately preceding paragraphs may further comprise selective erasing means for eliminating individual radiation scattering defects in said liquid crystal medium.

In accordance with the illustrated preferred embodiments, the present invention provides an optical, erasable, liquid crystal disc memory system. The system includes a storage disc in which two substrates containing the liquid crystal medium, preferably a smectic material, is configured for rotation about an axis. Writing onto the disc is accomplished during rotation by locally heating the liquid crystal with a pulsed, optical beam or array of beams to create radiation scattering defects forming the desired bit pattern.

In some preferred embodiments, several thin films attached to the substrates are used to establish the proper conditions within the liquid crystal medium for achieving the desired small "spot" (or defect) size and for performing erase functions in conjunction with the optical beam.

A system in accordance with the preferred embodiments overcomes many of the objections described in relation to the prior art erasable optical disc memories. It provides a locally erasable disc memory system capable of spot diameters less than 1 micron and stable center-to-center spot spacings of less than 3 microns. (Limitations in this regard are not presently inherent in the liquid crystal

system, but are a function of absorbing materials and beam focusing.) Individual data bits can be written and erased with laser pulses of the order of 50 ns at power levels commensurate with high duty cycle semiconductor diode lasers. A temperature storage range of -10°C and 40°C is easily achievable with commercially available liquid crystal mixtures, and with special mixtures a much wider range can be achieved. The system has the capability of disc sizes of up to 36 cms. and larger, although with these larger sizes some means of control such as grooves and internal spacers may be required. Furthermore, despite all previous indications to the contrary, the device has long term spot stability of the order of years, both dynamic and static.

There now follows a detailed description which is to be read with reference to the accompanying drawings of several embodiments of the present invention; it is to be clearly understood that these embodiments have been selected for description to illustrate the invention by way of example and not by way of limitation.

In the accompanying drawings:-

Figure 1 is a schematic illustration of an optical liquid crystal disc memory system;

Figure 2 is a flow sheet depicting the various states of the liquid crystal medium shown by cross-sections of a liquid crystal cell;

Figure 3 is a cross-section of a preferred embodi-

ment of the present invention, in the form of a liquid crystal disc;

Figure 4 is a cross-section of another preferred embodiment of the liquid crystal disc;

5 Figure 5 is a cross-section of yet another preferred embodiment of the liquid crystal disc; and

Figure 6 is a schematic illustration of a typical embodiment of the optical system used to perform read-write-erase functions in an optical liquid crystal disc memory
10 system.

Illustrated in Figure 1 is an optical liquid crystal disc memory system. It includes a liquid crystal disc memory (LCDM) 11 configured for rotation about a central axis B. The LCDM 11 typically ranges from 2.5 cms
15 to 18 cms in radius, and from 1 mm to 13 mm in thickness. The preferred liquid crystal medium for use for the LCDM 11 is typically smectic in phase. A servo motor and generator 21 are provided to rotate the LCDM 11 at a constant rate and to supply appropriate voltages across the LCDM 11. Also
20 illustrated are a movable optical system 41 and an optics translator 51. The optical system 41 converts electrical signals to optical signals and vice versa

and is used to write and read onto and from the LCDM 11. The optical system 41 is also used in conjunction with the generator 21 to locally erase the LCDM 11. The optics translator 51 moves the optical system to the appropriate location on the disc and mediates between the disc and a control device such as digital computer (not shown). The translator 51 also mediates between the control device and the optical system 41. A light source 61, e.g., an LED, also interconnected to the control device, and a photodetector 71 are included in order to optically switch the generator 21 when erase functions are required.

In practice, the method for reading, writing and erasing and LCDM 11 is well known in the art. As illustrated in Figure 2a, initial conditions are established wherein the LCDM 11 contains a smectic liquid crystal in a non-scattering or unwritten configuration so that it is transparent at the ambient operating temperature. Writing is accomplished by selectively heating small areas of the crystal to the isotropic state typically with a laser, and rapidly cooling back into the smectic state, thereby creating scattering centers 15 in those regions which were locally heated (see Figures 2b and 2c). The effect of writing is thus to create a pattern of spots (or bits) on an otherwise non-scattering background. Reading is accomplished by illuminating the liquid crystal (at a much reduced power level relative to the writing function) and

observing the scattered radiation to determine the bit pattern (see Figure 2d). Two kinds of erasing procedures are available, one for local erasure (Figure 2e), and the other for erasure of the entire disc (Figure 2f). For local erasure the local area is heated to the isotropic state and allowed to cool while applying a relatively low voltage (the magnitude being geometry and material dependent). Total erasure of the disc can be accomplished in several ways, all of which are well known in the art; for example, by heating the liquid crystal medium to the isotropic state and allowing it to cool back to the ordered (non-scattering) state in the presence of an electric field, or by subjecting it to a large uniform electric field.

Figure 3 shows a cross-section of a preferred embodiment of an LCDM 11. In this embodiment, light for both reading and writing functions is incident from above. As shown, the LCDM 11 includes two substrates 71 and 151, which together with spacers and sealing material (not shown) contain the liquid crystal medium between the substrates. Clearly, the substrate 151 must be transparent to the incident radiation used for reading and for writing. The substrates 71 and 151 are typically of the order of 1.5mm to 2mm in thickness, but can be thicker or thinner depending on the desired optical quality of the surfaces and mass of the disc. Several suitable materials for the substrates are

soda lime glass, polymethyl methacrylate or fused quartz. Many other materials could also be used provided their optical quality is controllable, they are relatively inert with respect to the liquid crystal medium, and they are sturdy enough to support other films and to withstand the forces resulting from rotation. Another aspect of this embodiment is that both substrates need not be made of the same material, e.g., only the upper substrate 151 need be transparent. The liquid crystal medium (LCM) 81 contained by the substrates 71 and 151 is typically smectic, although other phases may also prove stable under rotation. Suitable materials for the LCM 81 would be a mixture of alkyl and alkoxy cyanobiphenyls, such as those called "S1" and "S2" available from BHD Chemicals Ltd. In this particular embodiment, the LCM 81 is of the order of 10 microns in thickness; in general the minimum thickness of the liquid crystal material is determined by the characteristic size of scattering defects in the medium, its dielectric properties and the limitation of fabrication methods for obtaining uniform thickness and molecular orientation. Clearly, the optimal thickness will vary from one material to the next.

In order to enter information into and retrieve information from the disc, proper conditions must be established within the liquid crystal relative to the writing

and reading devices. In the embodiment of Figure 3, these conditions are established by using several layers of thin films attached to the substrates 71 and 151, six such films being shown. Film 111 is an alignment-passivation layer, typically in the range of 50-2000Å in thickness. Examples of suitable materials for the film 111 would be spun-on polyimide or plasma deposited SiO₂. The minimum thickness of the film 111 is determined by the minimum amount of material required to obtain uniform liquid crystal alignment, while the maximum thickness is typically limited by the requirement of good thermal communication between the LCM 81 and a film 101. In this particular embodiment, the film 111 serves to preferentially align the liquid crystal molecules in a direction parallel to the surface of the film. (In another embodiment, a different direction may be preferred.) This film, being an insulator, also serves to inhibit charge transport between the liquid crystal and the electrode-absorber-reflector layer, film 101; i.e., film 111 also serves a passivation function. In this particular embodiment, film 101, the electrode-absorber-reflector layer, may typically be a glassy metal such as 20% tungsten, 40% nickel and 40% tantalum by weight, although the composition could vary significantly depending on which function, i.e., absorber or reflector, is desired to be optimized. Acting as an electrode, the film 101 absorbs incident radiation from the

writing system, converting it to heat. As a reflector, the film 101 reflects incident radiation used in the reading system back through the liquid crystal and into the reading optics.

5 A film 91 is a heat control layer which serves to control the distribution of heat conducted from the film 101 to the liquid crystal, relative to heat conducted from the film 101 to the substrate. It also serves to control the heat distribution within the liquid crystal itself.

10 The thickness of the heat control layer ranges from 0.1 μ m to 5 μ m in this particular embodiment, but could vary more widely depending on the desired heat distribution, the material used for the layer, the power density of the incident radiation, and the desired spot size. Suitable

15 materials for the heat control layer are polyimide, SiO₂, or even a metal such as aluminum if it were desired to quickly absorb the heat from the film 101 and spread it over a larger area.

20 Film 121 is an alignment layer for aligning the liquid crystal molecules. The film 121 should be optically transparent and typically 50 $\text{\AA}$ to 1000 $\text{\AA}$ in thickness. Suitable materials include silane coupling agents, organic polymer films, and inorganic films such as SiO₂. Film 131 is another passivation layer to prevent charge transfer

25 between the liquid crystal and the electrode 141. A typical

material for the film 131 would be a transparent insulator such as polyimide. Clearly the film 131 could also serve as an alignment layer as does the film 111, thereby eliminating the film 121. However, the use of a separate film 121 illustrates that the chosen alignment directions on the upper and lower surfaces are decoupled and need not be same. The film 141 is a transparent electrode, typically of the order of $1000\text{\AA}$ in thickness, suitable materials including $\text{In}_{2-x}\text{Sn}_x\text{O}_3$, and Sb doped SnO_3 .

Figure 4 illustrates a cross-section of a second embodiment of the liquid crystal disc. In this embodiment, the description and function of elements 71, 81, 121, 131, 141 and 151 are as in the first embodiment depicted by Figure 3. Again radiation for reading, writing and erasing functions is incident from above. In this second embodiment, a film 92 is a heat control layer and an electrode. In addition, it acts in conjunction with a reflection control coating 102 as an absorber for the write and erase functions and as a reflector for the read function.

In this embodiment, the film 92 may be a metal such as aluminum of approximately $300\text{\AA}$ in thickness, the thickness being determined by the desired heat distribution. In this embodiment as in each of the others, an important consideration in selecting the material for the heat control layer is the desired temperature profile in both space and

time within the liquid crystal.

The specifics of the reflection control layer 102 are dependent on the index of refraction of the material used in the film 92, the wavelength of the radiation used for the read, write, and erase functions, and the relative absorbance/reflectance desired for the read, write and erase wavelength of 850nm, and a 50/50 split in absorbed and reflected light, a suitable material for the film 102 would be TiO_2 approximately 1000Å thick. Clearly, if another material such as gold were used for the film 92, the thickness of the film 102 would likewise vary. Also, it may be desirable to use a multilayer reflection control film such as a combination of MgF_2 and CeF_3 , especially if a two wavelength read-write system is contemplated. The film 102 may also be an insulator, and hence serve as a passivation layer as well.

Film 112 is an alignment layer, similar to the film 111 of the first embodiment, except that the film 112 does not also serve a passivation function. Suitable materials are polyimides or silane coupling agents.

Figure 5 depicts a cross-section of a third embodiment of liquid crystal disc which is configured so that radiation for reading is incident from above and radiation for writing and erasing is incident from below. In this embodiment, elements 71, 111, 81, 121, 131, 141 and 151 are as in the first embodiment which is depicted in Figure 3,

except that both substrates 71 and 151 must be transparent.

In this third embodiment, a film 103 is an electrode, reflector, and absorber, typically of a metal such as aluminum of the order of $1000\text{\AA}$ to $2000\text{\AA}$ in thickness. A

5 film 93 is an antireflection coating designed to optimize the absorption by the film 103 of radiation incident from below. For a glass substrate 71 and film 93 of aluminum with incident radiation at 850nm , a typical antireflection coating would be a three layer sandwich such as $1030\text{\AA}$ of
10 TiO_2 , $1550\text{\AA}$ of MgF_2 , and $875\text{\AA}$ of TiO_2 .

As can be seen from the above three embodiments of liquid crystal disc memory, the various films can perform multiple functions. Just as the number of films was reduced by combining several functions into one film, it may also be
15 possible to further reduce the number of films by appropriately doping the liquid crystal medium so that it becomes its own absorber. Additional embodiments will also occur to those skilled in the art.

Figure 6 depicts a typical read-write-erase
20 optical system which can be used with the first and second liquid crystal disc memory embodiments above. The system typically includes a pulses light source, in this case a semiconductor laser 201, a collimating system 191, a dark field stop/collector mirror 181, focusing optics 161 for
25 focusing the incident beam on the absorber layer of the

liquid crystal disc memory 11, and imaging optics for imaging the radiation reflected from the mirror 181 onto the detector system 51. In practice, this system also includes an automatic focus adjustment intimately related to the optics translator 51 of Figure 1 to compensate for variations in critical optical distances due to axial run-out, disc warpage, and disc thickness variations. Procedures for such focusing are well known in the art, for example, as described in U.S. Patent No. 4,051,519 entitled Focus Control System with Movable Mirror, and in U.S. Patent Application serial number 120,589, filed February 11, 1980, entitled Dynamic Focus Adjustment for Transmissive or Reflective Optical Disc Memory System, and references described therein.

Clearly, there are innumerable variations in the read-write-erase optical system depending on the particular focusing and imaging systems, whether separate systems are used for the read and write functions, and whether it is desired to optimize a portion of the system. For example, if it were desired to optimize the writing system, it is likely that an inverted dark field optical system would be used, i.e., the central writing beam would not be blocked as in the above description, and the light scattered out of the central beam direction would be gathered for the reading function. In the third embodiment, it is possible to optimize both the reading and the writing system independently.

For example, the reading system would be optimized by using a dark field optical system as described above, with a direct focused beam on the opposite side of the disc for writing and erasing. In this third embodiment, some care is required to ensure alignment of the reading and writing systems for proper track identification and following.

While in the preferred embodiments described above, the differences in optical scattering from ordered and disordered textures have been the primary mode for information-storage in the liquid crystal medium, other optical properties could also be applied to this function in a disc memory device, e.g., different optical polarization properties with respect to the polarizations of the incident radiation, differential absorption characteristics, or even luminescence could be utilized. Similarly, the use of patterned layers could also prove beneficial in the context of a liquid crystal disc memory. For example, patterned heat control layers would enable better control of the heat distribution in both space and time. Similarly, patterned electrodes could be used to reduce problems with capacitive reactance, thereby achieving faster switching times, or they could be used to total erase sectors rather than the entire disc. Patterning might also be used for track following and track identification purposes. Other properties of liquid crystals could also be beneficial; for example, photoconductor

addressed liquid crystals could be used to reduce the required laser power for the writing and erasing functions. Furthermore, writing functions should not be restricted to optical systems alone. Other radiation sources entirely, e.g., particle beam devices, may eventually prove beneficial in achieving smaller defect size.

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CLAIMS

1. An information storage and retrieval device comprising:

a liquid crystal disc memory comprising confinement means for confining a liquid crystal medium, said confinement means being configured for rotation about an axis; a liquid crystal medium confined by said confinement means, said liquid crystal medium having localized spots therein which act as radiation scattering centers, said spots being created by local heating of said liquid crystal medium and representing a desired pattern of information; reading means for detecting radiation scattered from individual spots; and rotating means for rotating said confinement means and said liquid crystal therein relative to said reading means, to provide high speed access to said information by said reading means.

2. A device according to claim 1 wherein said liquid crystal medium comprises a smectic liquid crystal.

3. A device according to either one of claims 1 and 2 further comprising:

at least two electrodes on said liquid crystal disc memory for applying an electric field to said liquid



crystal medium;

alignment means for aligning said liquid crystal medium; and

absorber means in thermal communication with said
5 liquid crystal medium for absorbing a portion of radiation
incident on said absorber means and for supplying energy
from said radiation to said liquid crystal medium.

4. A device according to claim 3 further
10 comprising reflector means for reflecting a portion of
radiation incident thereon.

5. A device according to claim 4 further
comprising heat control means for controlling the relative
15 distribution of energy conducted from said absorber means to
said liquid crystal medium and from said absorber means to
said confinement means.

6. A device according to any one of claims 3 to
20 5 further comprising heat control means for controlling the
relative distribution of energy transferred from said
absorber means to said confinement means and from said
absorber means to said liquid crystal medium.

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7. A device according to any one of claims 3 to 6 wherein said confinement means further comprises two substrates between which said liquid crystal medium is sandwiched.

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8. A device according to claim 7 wherein:
said electrodes are located opposite each other
with said liquid crystal medium therebetween; and
said alignment means and absorber means are
10 comprised of at least one film located between said substrates.

9. A device according to either one of claims 7 and 8 wherein said heat control means comprises at least one
15 film located between said liquid crystal medium and at least one of said substrates.

10. A device according to any one of claims 7 to 9 wherein said reflector means comprises at least one film
20 located between said liquid crystal medium and at least one of said substrates.



11. A device according to any one of the preceding claims may further comprise:

means for writing information onto said disc memory and/or erasing information stored on said disc
5 memory.

12. A device according to claim 11 further comprising writing means for locally irradiating a small area of said liquid crystal medium to create radiation
10 scattering defects therein.

13. A device according to either one of claims 11 and 12 further comprising selective erasing means for eliminating individual radiation scattering defects in said
15 liquid crystal medium.

14. An information storage and retrieval device substantially as hereinbefore described with reference to the accompanying drawings.

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